X(5) Critical–Point Behavior

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Notable benchmarks of collective nuclear behavior are the harmonic vibrator, the symmetrically deformed rotor, and the triaxially soft rotor. They correspond to limits of the Interacting Boson Model (IBM). While nuclei may display behavior near these idealized limits, many lie in transitional regions between them. Algebraic descriptions of the nature of the transition have been developed in direct analogy with classical phase transitions. Recently, it has been suggested that a useful approach is to apply the idea of a critical point of the shape change as a new benchmark against which nuclear properties can be compared. In particular, the transition from a spherical harmonic vibrator to an axially deformed rotor has been described analytically [1] by introducing a dynamic symmetry, denoted as X(5), which arises when the potential in the Bohr Hamiltonian is decoupled into two components – an infinite square well potential for the quadrupole deformation parameter, β, and a harmonic potential well for the triaxiality deformation parameter, γ. This is an approximation of the 'true' potential found at the critical point of the shape change from the IBM calculations.

Several empirical examples of nuclei that may be close to an X(5) critical point have been suggested including ^{152}Sm (Z=62, N=90) [2]. We showed in a recent paper [3] that some of the properties of the proposed candidates (including ^{152}Sm), specifically the energy spacings of the non–yrast states and the intersequence transition strengths, are not accurately reproduced by the X(5) description and that alternatives such as band–mixing models cannot be ruled out.

If the X(5) description is to be taken as a benchmark for describing shape transitional behavior, then it is important to find nuclei which follow the predicted behavior closely. Motivated by such considerations we have searched the Evaluated Nuclear Structure Data File (ENSDF) for examples of even–even nuclei, with Z$\geq$20, N$\geq$20, which display the predicted characteristics of the X(5) critical point description [4].

The experimental signatures for X(5) behavior are: a) the energies of the yrast states, E(I_1^+), should show characteristic ratios lying between those of a vibrator and a rotor; b) the strength of transitions between yrast states as reflected in the B(E2;I$\rightarrow$I-2) values should increase with angular momentum, I, at a rate intermediate between the values for a vibrator and rotor; c) the position of the first excited collective 0_2^+ state is 5.67 times the energy of 2_1^+ level; d) the non–yrast states based on the 0_2^+ level have larger energy spacings than the yrast sequence; e) the B(E2;I$\rightarrow$I-2) values for intrasequence transitions should be lower for the non–yrast sequence relative to those of the yrast sequence (these latter two points reflect the fact that the non–yrast states have a lower expectation value of β deformation than the states in the yrast sequence); f) intersequence B(E2) values should show a characteristic pattern. We used all of the above points in our search for nuclei displaying behavior similar to the X(5) predictions.

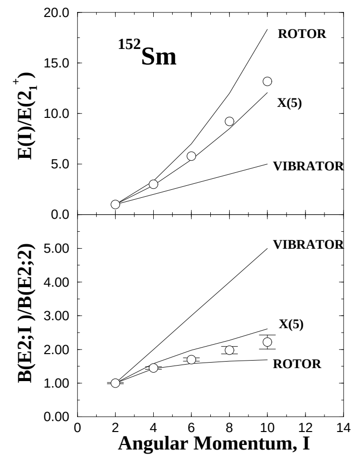

FIG. 1: Top panel: plot of the normalized energies for the yrast sequence in ^{152}Sm compared with the expected values for a harmonic vibrator, an axially deformed rotor, and the X(5) description. Bottom panel: plot of the normalized B(E2;I$\rightarrow$I-2) values for the transitions in the yrast sequence of ^{152}Sm compared to the expected values for a harmonic vibrator, an axially deformed rotor, and the X(5) description.

On the basis of the yrast state energies and yrast intraband transition strengths (see figure), the best candidates were found to be ^{126}Ba, ^{130}Ce, and the N=90 isotones of Nd, Sm, Gd, and Dy. While the X(5) picture reproduces the position of the first excited 0_2^+ in the N=90 isotones, none of these nuclei display the predicted behavior of either the energy spacings of the excited states or the intersequence transition strengths.

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